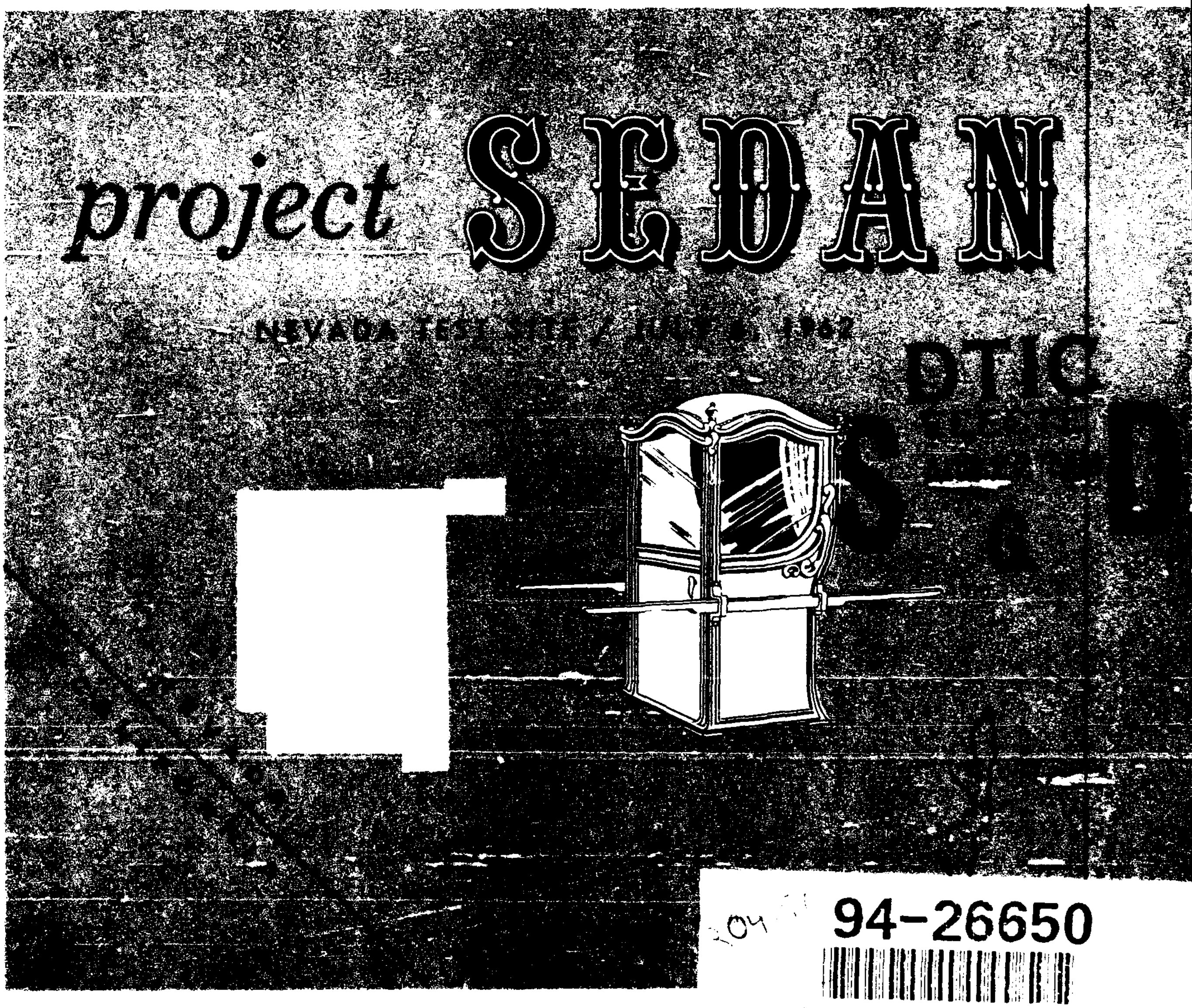
R. W. HENNY

PNE-215F

FINAL REPORT

Plowshare / peaceful uses for nuclear explosives

UNITED STATES ATOMIC ENERGY COMMISSION / PLOWSHARE PROGRAM



Structure Response

S. E. Warner / J. T. Cherry

LAWRENCE RADIATION LABORATORY

ISSUED: NOVEMBER 27, 1964

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NUCLEAR EXPLOSIONS – PEACEFUL APPLICATIONS

PROJECT SEDAN
PNE 215F

STRUCTURE RESPONSE

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S. E. Warner (Part I)
J. T. Cherry (Part II)

Lawrence Radiation Laboratory
Livermore, California

June 1964

ABSTRACT

The response of structures to ground motion resulting from underground nuclear explosions is dictated at least by a) structural characteristics, b) ground motion, and c) coupling between ground and structure. This report gives the performance of a simple mechanical oscillator of known structural characteristics, and lists measured ground motions at the oscillator resulting from the Sedan event. From ground motion data and oscillator characteristics, oscillator performance is predicted. A comparison of expected results with actual oscillator performance completes the report.

CONTENTS

INTRODUCTION

The Sedan event, a 100-kt nuclear detonation, occurred on July 6, 1962, at the Nevada Test Site. It was scheduled as a cratering experiment to study effects of nuclear explosives in relation to the Plowshare program.

An effect of large buried explosions that is of interest to the Plowshare program is the production of wave motion in the earth. Effects on structures, particularly structures for public occupancy, of motion of the earth's surface resulting from Plowshare detonations are an economic as well as technical concern of the program. The effect on structures of natural earthquake motion is voluminously documented, and from this experience many experimental techniques are suggested for determining the response of structures to ground motion. A technique that has found large favor and reward is the use of models.

This experiment was designed to study the response of a model structure exposed to ground motions of structural significance resulting from the Sedan event. Selection of a mechanical oscillator of one degree of freedom simplified simulation of structural characteristics. The important criteria relating structures to model were:

a. Structural period, approximately 1/2 sec.

b. Structural damping, approximately 5% of critical damping.

PART I. EXPERIMENTAL PROCEDURE

EQUIPMENT

Oscillator construction was as shown in Figure 1.1. Field installation was as shown on Figures 1.2 and 1.3. Ground motions and oscillator performance at the several locations resulting from the event were determined using strain gage

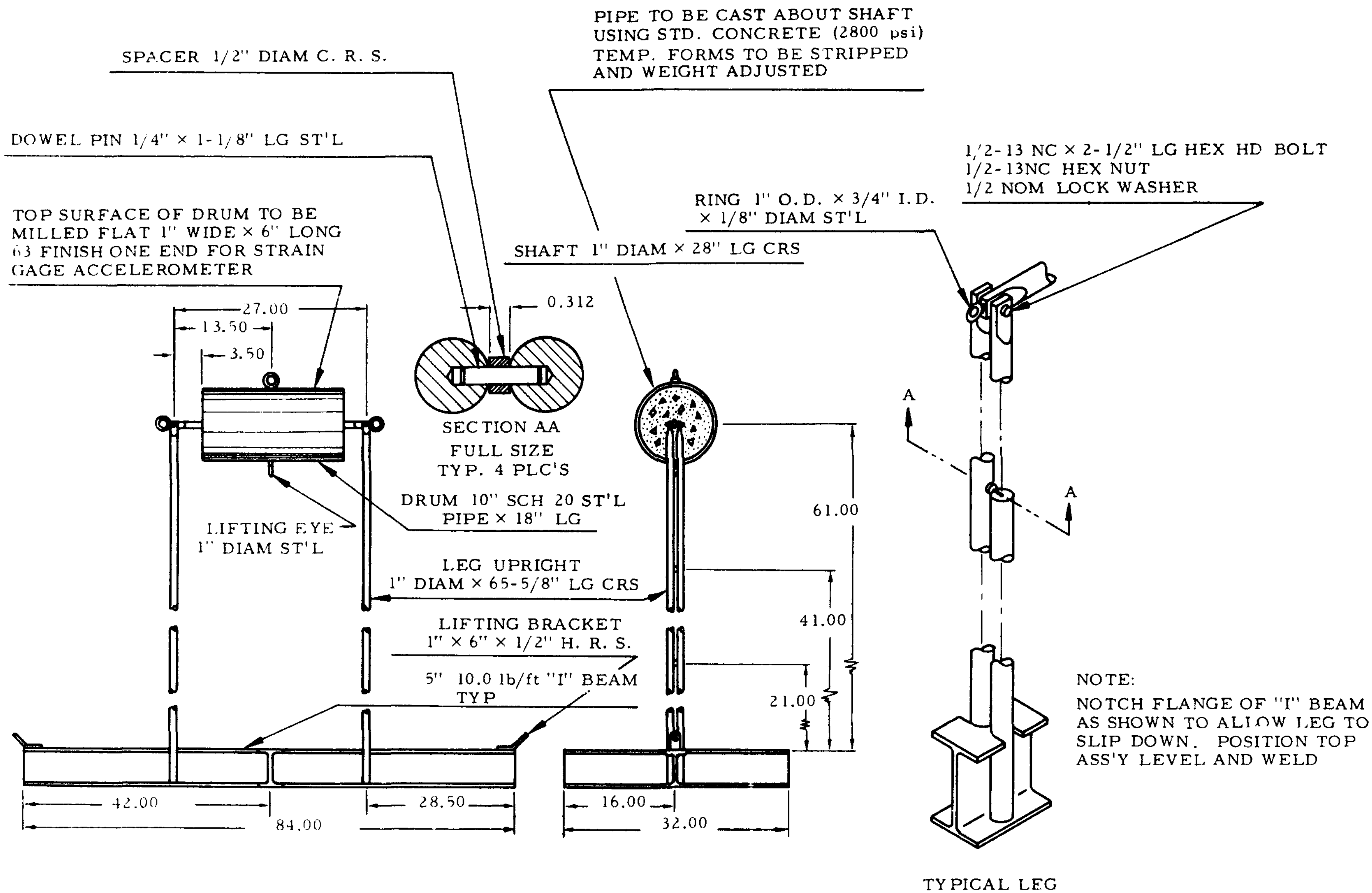

Figure 1.1 Oscillator construction.

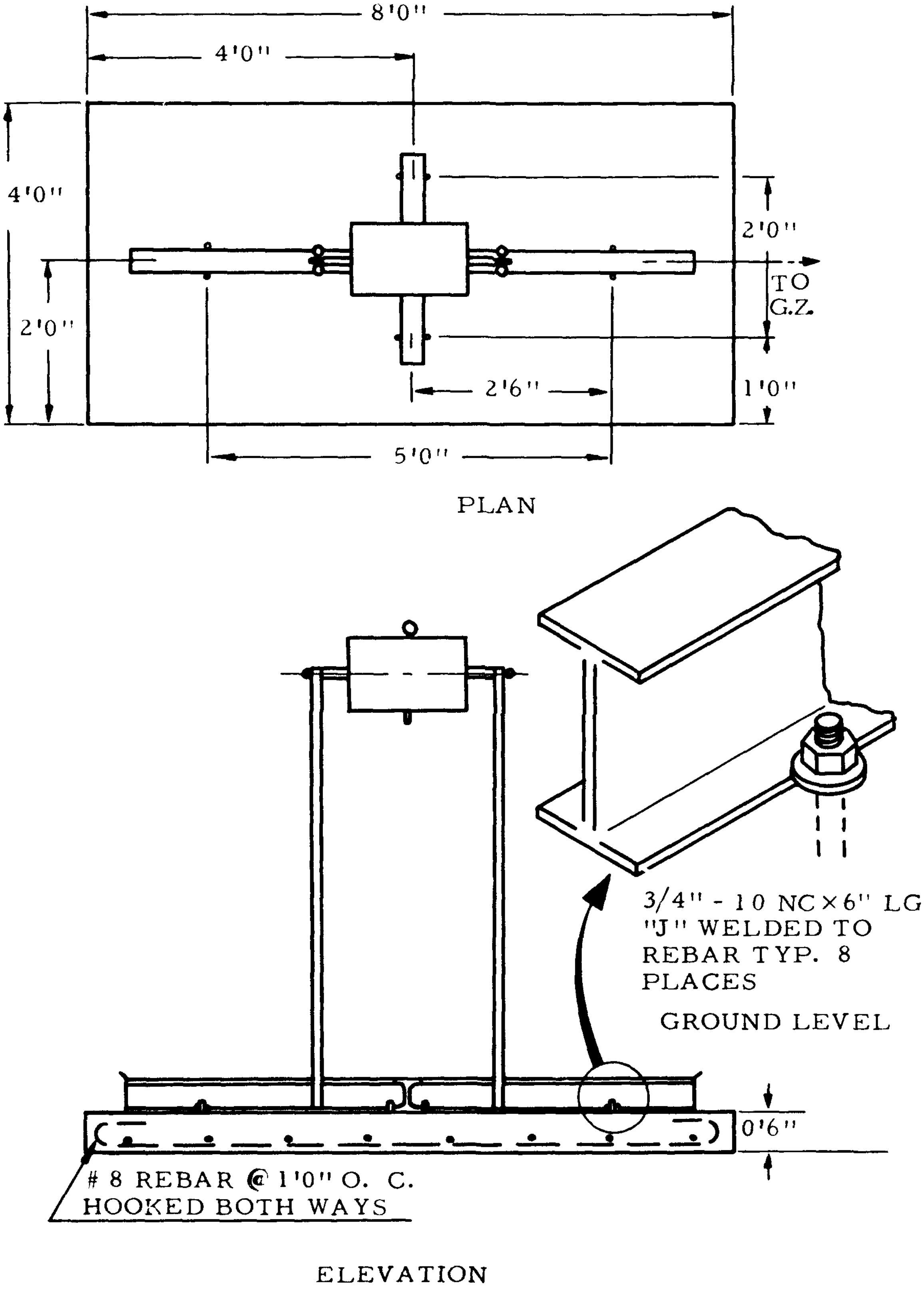

Figure. 1.2 Oscillator field installation.

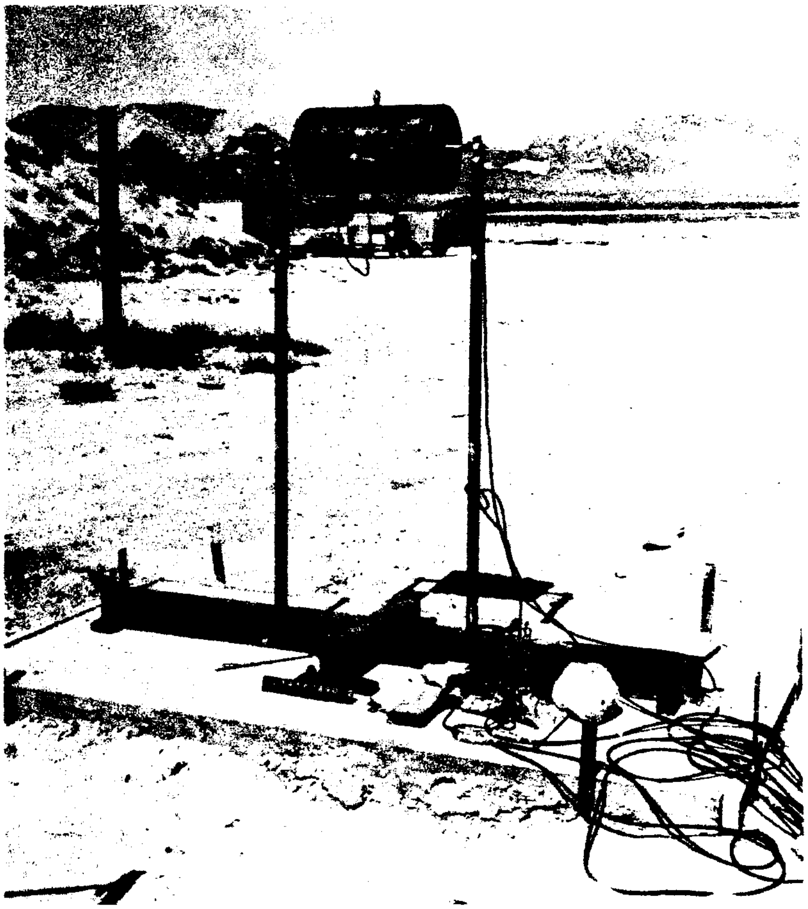

Figure 1.3 Typical as-built installation.

(Statham) accelerometers with galvanometric (Visicorder) recording. At the two distant stations FM (Ampex) tape recording was also used.

PROCEDURE

System installation and readiness were handled by LRL-Support Division personnel. Field construction was handled by LRL-Nevada personnel. Accelerometers were calibrated dynamically before field installation. Ranges provided at selected field locations were expected to insure at least one useful record, allowing for at least a factor of two between design and actual event performance. After completion of the installation, channel sensitivities were determined as connected by "turn over" tests of the accelerometers. Preliminary dynamic oscillator characteristics were determined by recording the output of the accelerometers attached to oscillators allowed to decay naturally from an initial displacement. Spring constants were determined by direct force-deflection measurements. Viscous damping was approached using rubber washers under appropriate compression at the pin connections of the oscillator frame. At shot time, all recorders were started remotely with a minus 2 sec timing signal and stopped near the end of record stock by preset disconnects. On re-entry all records were collected and all equipment was recovered successfully.

RESULTS

The event provided seismic activity approximately an order of magnitude below the predicted level. As a consequence, recording at the more distant location, while successful, is of academic interest only. At the near location (Station 18, USC&GS) 7500 ft distant from ground zero, useful records were obtained for both ground and oscillator motion. The maximum single amplitude ground acceleration obtained was 0.08 g in the radial direction. The maximum single amplitude acceleration observed on the oscillator mass was 0.32 g in the radial direction.

The record from Station 18 had four active data channels as given below, including trace amplitude scale factors:

a) Oscillator radial acceleration, 2.51 cm/g

b) Ground radial acceleration, 2.54 cm/g

c) Ground vertical acceleration, 1.32 cm/g

d) Ground transverse accelerations, 1.29 cm/g

The record paper speed was approximately 25 in./sec. The 100-cps timing provided 10 msec timed intervals on the record.

Record processing has been done manually. Scaled amplitudes of radial acceleration were obtained at 10-msec intervals between 1 and 2.5 sec after zero time, covering the period of peak accelerations. These were converted to accelerations using the scale factors given above. Reduced radial accelerations and elapsed times after reference zero time are presented in Table 1.1.

TABLE 1.1 PEAK ACCELERATIONS

Ref. Time (sec)	Ground Accel. (g)	Mass Accel. (g)	Ref. Time (sec)	Ground Accel. (g)	Mass Accel. (g)
1.00	+0.016	-0.024	1.39	-0.043	--
.01	+.022	--	.40	-.025	+0.067
.02	+.024	-.023	.41	-.017	--
.03	+.022	-.025	.42	-.012	+.082
.04	+.013	-.034	.43	-.004	+.094
.05	+.003	-.035	.44	-.004	+.119
.06	-0.002	-.027	.45	+0.008	+.116
.07	-.016	-.024	.46	+.019	+.125
.08	-.013	-.024	.47	+.023	+.110
.09	-.009	--	.48	+.023	+.112
.10	-.004	-.019	.49	+.023	--
.11	+0.008	--	.50	+.016	+.076
.12	-0.004	--	.51	+.015	--
.13	0	--	.52	+.042	--
.14	+0.004	--	.53	+.048	--
.15	+.011	-.017	.54	+.047	--
.16	+.009	--	.55	+.046	-0.003
.17	+.013	+0.032	.56	+.033	--
.18	+.018	+.033	.57	+.029	--
.19	+.020	+.043	.58	+.015	--
.20	+.017	+.022	.59	+.011	--
.21	+.019	+.024	.60	+.002	-0.112
.22	+.025	+.030	.61	-0.008	--
.23	+.030	+.020	.62	-.005	-.138
.24	+.026	--	.63	-.015	-.148
.25	+.018	+.006	.64	-.007	-.161
.26	+.010	--	.65	-.009	-.161
.27	-0.006	-0.016	.66	-.015	-.136
.28	-.020	-.015	.67	-.007	-.133
.29	-.029	-.014	.68	-.023	-.109
.30	-.041	-.031	.69	-.021	--
.31	-.054	-.030	.70	-.019	-.079
.32	-.065	-.023	.71	-.018	--
.33	-.081	-.021	.72	-.025	--
.34	-.080	--	.73	-.033	--
.35	-.066	-0.010	.74	-.024	--
.36	-.066	--	.75	-.033	+0.054
.37	-.063	--	.76	-.036	--
1.38	-0.059	--	1.77	-0.039	--

TABLE 1.1 PEAK ACCELERATIONS (Continued)

Ref. Time (sec)	Ground Accel. (g)	Mass Accel. (g)	Ref. Time (sec)	Ground Accel. (g)	Mass Accel. (g)
1.78	-0.038	--	2.16	-0.012	--
.79	-.032	--	.17	-.001	+0.248
.80	-.033	+0.173	.18	+0.018	+.278
.81	-.023	--	.19	+.026	+.304
.82	-.008	+.200	.20	+.038	+.301
.83	0	+.210	.21	+.038	+.316
.84	+0.015	+.205	.22	+.043	+.305
.85	+.020	+.200	.23	+.039	+.297
.86	+.036	+.177	.24	+.035	--
.87	+.041	+.171	.25	+.029	+.243
.88	+.055	+.145	.26	+.017	--
.89	+.071	--	.27	+.005	--
.90	+.068	+.082	.28	-0.005	-
.91	+.079	--	.29	-.017	--
.92	+.083	--	.30	-.016	+.028
.93	+.082	--	.31	-.030	--
.94	+.074	--	.32	-.031	--
.95	+.064	-0.133	.33	-.033	--
.96	+.064	--	.34	-.041	--
.97	+.044	-.197	.35	-.045	-0.179
.98	+.036	-.242	.36	-.056	--
.99	+.026	-.258	.37	-.048	-.220
2.00	+.005	-.274	.38	-.053	-.233
.01	+.010	-.292	.39	-.048	-.234
.02	-0.012	-.284	.40	-.050	-.235
.03	-.014	-.291	.41	-.042	-.223
.04	-.026	-.280	.42	-.034	-.205
.05	-.034	-.262	.43	-.037	-.195
.06	-.032	--	.44	-.030	--
.07	-.036	--	.45	-.024	-.126
.08	-.035	--	.46	-.024	--
.09	-.046	--	.47	-.013	--
.10	-.046	-.078	.48	-.017	--
.11	-.043	--	.49	-.005	--
.12	-.044	--	2.50	-.006	+0.069
.13	-.036	--			
.14	-.036	--			
2.15	-.020	+0.162			

Oscillator damping ratio and period during Sedan at Station 18 were determined as listed below from recorded oscillator performance after peak ground motion had passed. Since the damping was approximately 4% of critical damping, the difference between the damped and undamped natural period is neglected in determining the performance of the oscillator. System constants prevailing are:

Damped period, T_0	0.3835 sec
Spring constant, K	862.8 lb/ft
Damping factor, n	0.679 sec^{-1}
Damped frequency, $w = \frac{6.2832}{0.3835}$	16.384 rad/sec
Spring mass, $m = \frac{862.8}{(16.384)^2}$	3.214 $lb\text{-}sec^2/ft$
Damping, % critical $\frac{0.679(100)}{16.384}$	4.1%

PART II. DATA ANALYSIS

METHODS

The data resulting from the experiment include 1) constants determined for the oscillator system, 2) measured acceleration-time history of the oscillator mass, and 3) measured acceleration-time history of the ground. These accelerations are listed in Table 1.1.

The constants of the oscillator system determine the impulse response of the oscillator mass. By convolving this impulse response with the measured time history of ground acceleration, a prediction of the time history of acceleration of the oscillator can be obtained for comparison with the recorded mass acceleration.

To obtain the impulse response of the oscillator we write its equation of motion

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = 0, \tag{1}$$

where x is the displacement of the mass and y is the displacement of the base. Then, if $\ddot{y}$ is the standard unit impulse we have

$$y = \begin{cases} 0, & t < 0 \\ t, & t > 0 \end{cases} \qquad \dot{y} = \begin{cases} 0, & t < 0 \\ 1, & t > 0 \end{cases} \tag{2}$$

Substituting Equation (2) into Equation (1) and taking the Laplace transform of (1) gives

$$s\bar{\ddot{x}} = \frac{c}{m}\left[\frac{s^2 + \frac{k}{c}s}{s^2 + \frac{c}{m}s + \frac{k}{m}}\right] \tag{3}$$

The inverse of Equation (3) is available in most Laplace transform tables and is equal to

$$\ddot{x} = \frac{2A}{u}\left[(a - A)^2 + u^2\right]^{1/2} e^{-At} \sin(ut + \phi) \tag{4}$$

where

$$A = \frac{c}{2m}$$

$$u = \left[\frac{k}{m} - A^2\right]^{1/2}$$

$$a = \frac{k}{c}$$

$$\tan \phi = \frac{u}{a - A}$$

RESULTS

Equation (4) is the desired impulse response of the oscillator. This response is shown in Figure 2.1 for oscillator constants

$$m = 3.214 \ \frac{\text{lb-sec}^2}{\text{ft}}$$

$$c = 4.36 \ \frac{\text{lb-sec}}{\text{ft}}$$

$$k = 862.8 \text{ lb/ft.}$$

This impulse response was convolved with the ground acceleration of Figure 2.2. The result of this convolution is shown in Figure 2.3 and represents the predicted acceleration of the mass when the base is subjected to the acceleration of Figure 2.2. The data of Table 1.1 are also plotted in Figure 2.3. Agreement between the predicted and measured values of acceleration is within 15%.

$$\int_0^t h(t-\tau) f(\tau)\, d\tau$$

$f(\tau)$

$h(t-\tau)$ = response ... at time ... due to a unit impulse ...

/mr

τ t τ

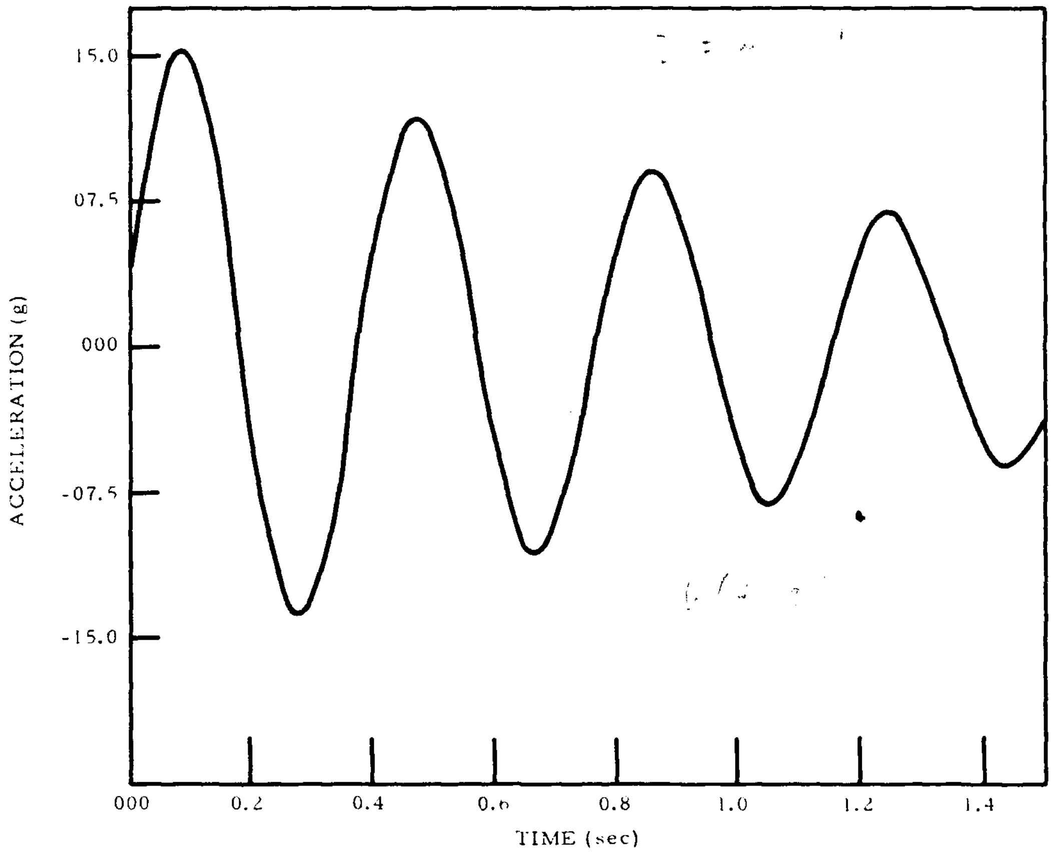

Figure 2.1 Impulse response.

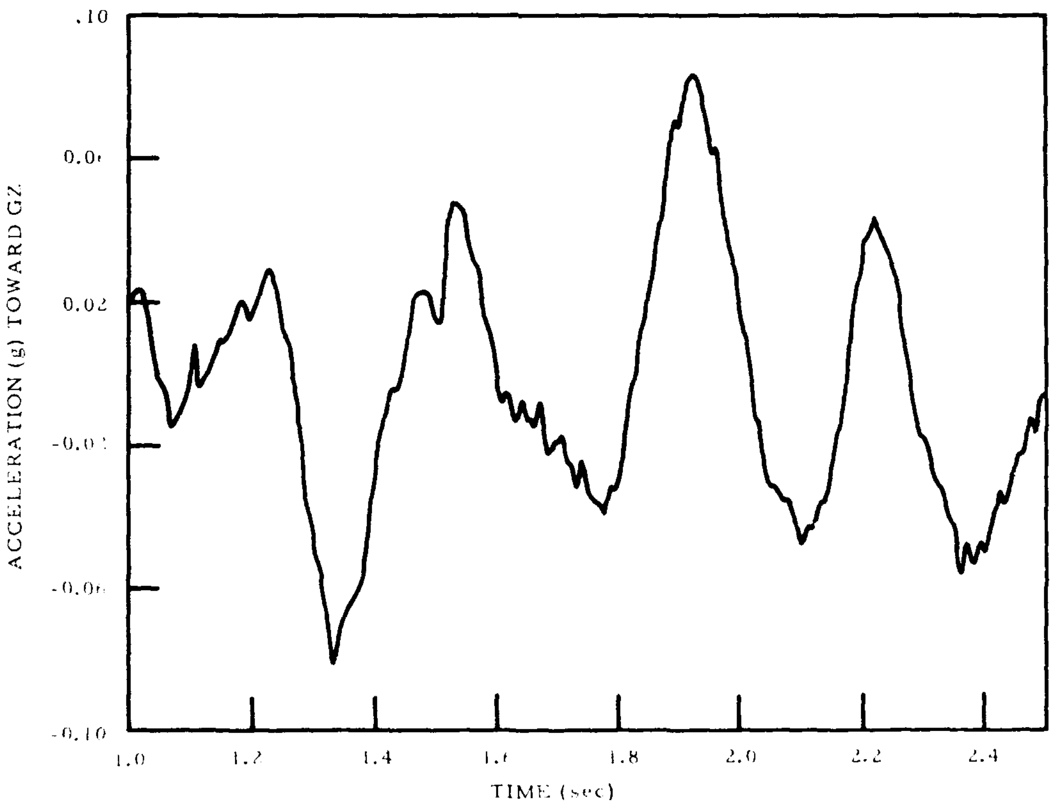

Figure 2.2 Ground acceleration.

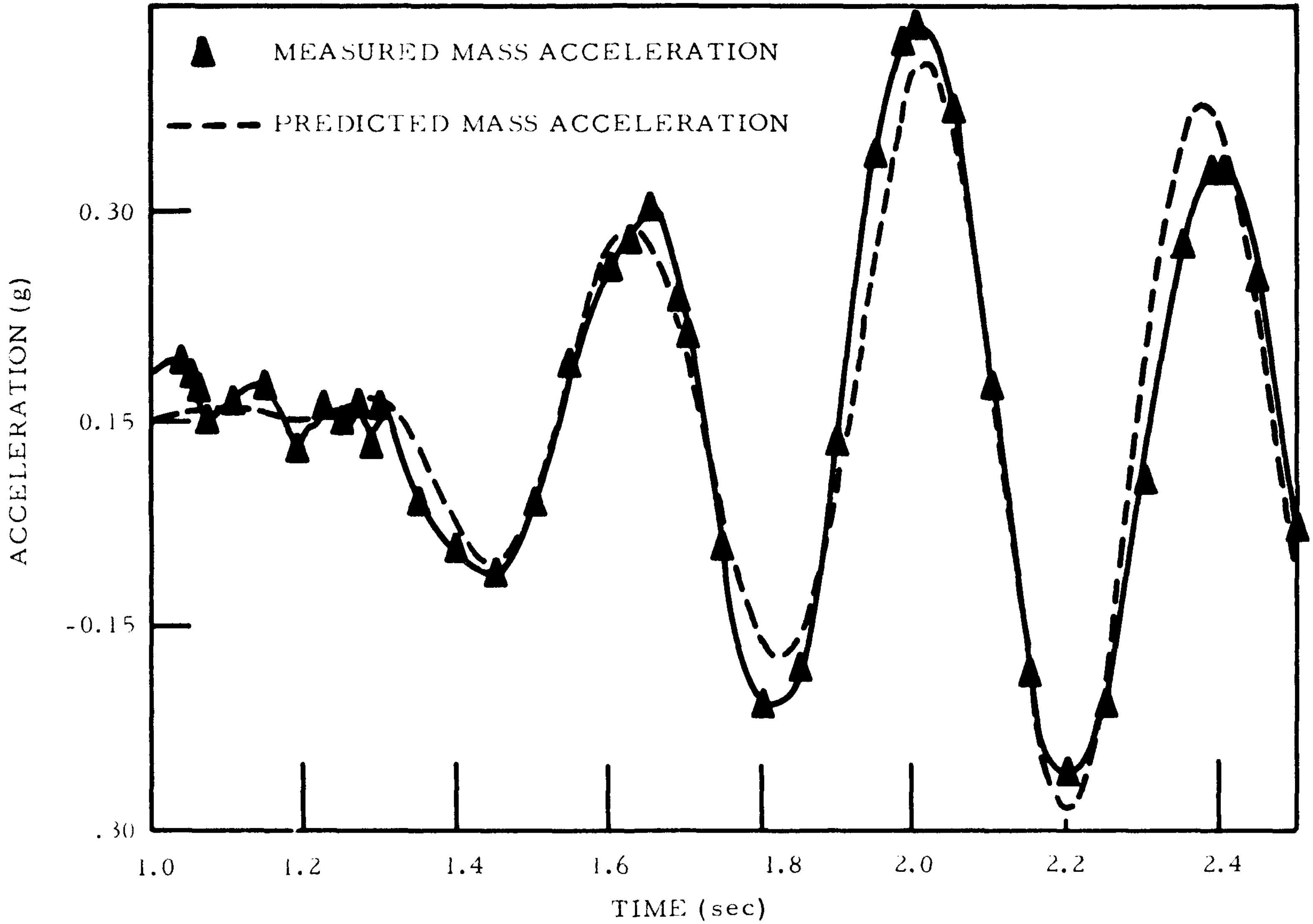

Figure 2.3 Measured and predicted mass acceleration.

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ABBREVIATIONS FOR TECHNICAL AGENCIES

STL	Space Technology Laboratories, Inc., Redondo Beach, Calif.
SC	Sandia Corporation, Sandia Base, Albuquerque, New Mexico
USC&GS	U. S. Coast and Geodetic Survey, San Francisco, California
LRL	Lawrence Radiation Laboratory, Livermore, California
LRL-N	Lawrence Radiation Laboratory, Mercury, Nevada
Boeing	The Boeing Company, Aero-Space Division, Seattle 24, Washington
USGS	Geological Survey, Denver, Colorado, Menlo Park, Calif., and Vicksburg, Mississippi
WES	USA Corps of Engineers, Waterways Experiment Station, Jackson, Mississippi
EGG	Edgerton, Germeshausen, and Grier, Inc., Las Vegas, Nevada, Santa Barbara, Calif., and Boston, Massachusetts
BYU	Brigham Young University, Provo, Utah
UCLA	UCLA School of Medicine, Dept. of Biophysics and Nuclear Medicine, Los Angeles, Calif.
NRDL	Naval Radiological Defense Laboratory, Hunters Point, Calif.
USPHS	U. S. Public Health Service, Las Vegas, Nevada
USWB	U. S. Weather Bureau, Las Vegas, Nevada
USBM	U. S. Bureau of Mines, Washington, D. C.
FAA	Federal Aviation Agency, Salt Lake City, Utah
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